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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Manufacturing structured elements

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MANUFACTURING STRUCTURED ELEMENTS

FIELD OF THE INVENTION

The invention is in the field of manufacturing micro-structured elements such as micro-optical elements or micro-optical systems. It also extends to MicroElectroMechanical Systems (MEMS) and combined micro-optical and electronical and/or mechanical systems such as MicroOptoElectroMechanical Systems (MOEMS). More concretely, it deals with a method of replicating – for example by an embossing or molding process – an element into a micro-structured element, with a replication tool, and with a method of manufacturing a replication tool.

BACKGROUND OF THE INVENTION

Micro-optical elements have gained increasing importance. Micro-optical elements here are elements of any kind that rely on micro-optics. The term 'micro-optical elements' here includes systems comprising electronical and/or mechanical components, such as, for example, the MOEMS. Micro-optics, as opposed to conventional optics, is based on fine structures causing refraction and/or diffraction, the structures having characteristic depths/heights and often also widths of typically a few micrometers, for example of 0,5 μm - 200 μm, preferably of between 1 μm and

about 50 µm or between 1 µm and about 30 µm. In other words, the characteristic profile depths and the profile widths are of the order of a few wavelengths up to a few tens of wavelengths for refractive optics and of about one wavelength up to a few wavelengths for diffractive optics. As a rule of thumb, micro-optical elements have structures such that the phase relation of radiation present at different neighboring places on the structure is well-defined. This is opposed to classical, purely refractive optical elements, where the behavior of the radiation at different elements of the structure can be described in a geometrical optics picture. Micro-optical elements, thus, as opposed to classical optical elements (such as classical lenses, mirror elements etc.) can be regarded as having structures which are such that the wave nature of the light has to be taken into account and participates in the effect the micro-optical element has upon radiation.

For manufacturing state of the art Diffractive Optical Elements (DOEs; being an example of Micro-Optical Elements), different methods are known. A first method is the manufacturing of a resist pattern using conventional photostructuring or electron beam structuring techniques relying on masks or the like. The resist pattern is used as a diffractive element. A second method includes the forming of a resist pattern using one of the mentioned techniques and then etching the substrate such that a diffraction element having a desired blazed shape is produced.

Other methods, such as the one disclosed in JP-A-168601/1988 rely on etching including structuring an etching stopper layer with a photolithographic process.

All these state of the art methods have in common that they are not very suitable for mass production, since the manufacturing of every element involves a series of elaborate production steps.

Therefore, it is an objective of the invention to provide a method of forming a micro-structured element which is suitable for producing micro-optical elements and overcomes drawbacks of prior art manufacturing methods. It should provide a good definition of the 3D-structural features and their absolute dimensions and positions, even if the micro-structured element is large or if an array of micro-structured elements is manufactured.

SUMMARY OF THE INVENTION

According to the invention, a structured (or micro-structured) element is manufactured by replicating/shaping (molding or embossing or the like) a 3D-structure in a preliminary product using an replication tool. The replication tool comprises a spacer portion protruding from a replication surface.

The replica (the micro-structured element, for example the micro-optical element or micro-optical element component or an optical micro-system) may be made of epoxy, which is cured – for example UV cured – while the replication tool is still in place. UV curing is a fast process which allows for a good control of the hardening process.

The replication process may be an embossing process, where the deformable or viscous or liquid component of the preliminary product to be shaped is placed on a surface and then the replication tool is pressed against this surface. As an alternative, the replication process may be a molding process.

The spacer portion is preferably available in a manner that it is 'distributed' over at least an essential fraction of the replication tool, for example over the entire

replication tool or at the edge. This means that features of the spacer portion are present in an essential fraction of replication tool, for example, the spacer portion consists of a plurality of spacers distributed over the replication surface of the replication tool.

The spacers allow for an automated and accurate thickness control.

The replication tool may comprise material with some elasticity, for example PDMS or an other elastic material. Then, it gives a conformal thickness control even if the surface, on which the process is executed is not perfectly planar, or if the replication tool is not perfectly planar. It should be noted that for many applications of micro-optical elements, planarity has to be ensured with a precision of up to around 1 μm or even more precise. In other words, for micro-optical elements, the height of the features – the z position in a coordinate system where the tool surface defines the xy-plane – should preferably be defined with an accuracy of 1 micron or more.

The replication tool may further comprise a rigid back plate to make it dimensionally stiff on a large scale.

The spacer portion may be present anywhere where no optical function is located.

According to a special embodiment, spacers may be placed in corners and/or at edges of the final replica in order to decrease the stress concentration.

According to yet another special embodiment, the spacer portion may be laid out in a manner that the fluid dynamic effects during the replication process is optimized. For

example, the spacers can be designed in order to form a barrier to the flow of uncured deformable replication material at the edge of the substrate. Alternatively, their shape and distribution can be such that it directs the flow of the deformable replication material during the embossing process, for instance to fill a rectangular replication area uniformly and completely.

The invention also features a method of manufacturing a replication tool using a master or sub-master and a method of equipping an existing master or sub-master with a spacer portion.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, embodiments of the invention are discussed with reference to drawings. The figures in the drawings are all schematic. They show the following:

Fig. 1: A cross section through a replication tool according to the invention.

Figs. 2, 3 and 4: Process steps in a process for manufacturing a micro-optical element.

Figs. 5-8: Process steps in a process for manufacturing a master for a replication tool.

Figs. 9-13: Process steps in a process for manufacturing sub-master for a replication tool.

Figs. 14-16: Process steps in a process for manufacturing a replication tool from a master or sub-master.

Figs. 17 and 18: Examples of bottom views (i.e. views on the replication surface) of replication tools.

Fig. 19 a replication tool with alignment means.

Figs. 20 and 21 examples of processes for double-sided replicating.

Fig. 22 an example of a multilevel tool with mechanical features.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The replication tool 1 shown in **Figure** 1 comprises a replication surface 1a with negative structural features being a negative of structural features to be shaped on a surface of a micro-optical element. More concretely, the embodiment shown very schematically in the figures has indentations 1b corresponding to protrusions of a surface of a micro-optical element. Typical dimensions (characteristic depths/heights and often also widths) of the structural features are a few micrometers, for example 0,5 µm - 200 µm, preferably between 1 µm and about 50 µm or between 1 µm and about 30 µm. The replication tool further has spacers 1c protruding from the replication surface. The height h of the spacers is for example between 2 µm and 1000 µm, preferably between 2 µm and 200 µm, for example between 10 µm and 40 µm, and it usually is such that the spacers protrude further than the highest

negative structural features. The geometrical dimension (shape, height, diameter) and the distribution of the spacers can be an important parameter in the system design as well as in the process development. The optical function can be fine tuned with a proper spacer design. More generally, the desired optical function also implies a certain maximum tolerance. Especially if the fabricated micro-optical (or other) structured element is large in size, these maximum tolerances may be strict. The method according to the invention allows to design a tool satisfying these conditions. Depending on the physical properties of the replication material, the spacer properties will be adapted to guarantee a good processing.

The replication tool 1 is for example made of a material with some elasticity. It may be made of PDMS, or of an other elastic or stiff – curable or thermoplastic polymer or other formable material. It may, as an alternative, also be made of a metal, such as a Ni alloy or a an alloy of an other transition element or an other metal. It may also be made of semiconductor material (such as an etched wafer) or of an insulating crystalline material. The replication tool 1 in Fig. 1 for reasons of simplicity is drawn as one homogeneous body, in practice, it may be made up of several material layers or components. For example, the structural features and/or the spacers may be made of a material different from the tool body, and the tool may further comprise stiffening carrier elements as shown below or other elements. The replication tool may, according to yet another alternative, be composed of an elastic layer and a stiffer, patterned layer which carries the desired pattern.

A process for forming a micro-optical element is very schematically shown in Figures 2 - 4. A replication tool 1 is brought into contact with a preliminary product 2 having, at a surface, a material component 3 which is in a deformable state (Fig. 2). The preliminary product 2 further comprises a second material component 4 which is dimensionally stiff. The replication tool is pressed against the deformable material component 3 up to the point where the spacers abut a surface of the dimensionally

stiff material component 4 (Fig. 3). Said surface thus serves as a stop face for the pressing. As an alternative to the shown embodiment, a stop face may also be formed by other ways. For example, the preliminary product 2 does not have to comprise a dimensionally stiff component but may as an alternative be placed on a stiff carrier, such as a glass plate or the like. Where the replication tool is still in place, the deformable material component 3 may be hardened, for example by illumination with appropriate radiation 5 (Fig. 4), by heating, by cooling, by exposing to oxygen, by waiting during a certain time for letting it dry, or the like, etc., depending on the nature of the deformable material.

Figs. 5 - 8 schematically outline a preferred method of manufacturing a replication tool of the kind shown in Fig. 1. An original 11 comprises the (positive) structural features that are required for the micro-optical element to fulfil its function. The original is provided with an etch resist layer 12 that is structured (Fig. 6), for example in a conventional manner by photolithographic techniques. The structure of the resist layer 12 corresponds to a negative of the pattern, in which the spacers 1c are arranged. As a next step, negative structures for the spacers are etched into the original 11, for example by a plasma with the Reactive Ion Etching (RIE) technique (Fig. 7). The resist layer 12, in this process, serves as an etch resist. Then, the resist layer 12 is stripped from the resulting master 11' (or sub-master). The replication tool 1 (Fig. 8) is obtained by replicating the master, for example molding or embossing (if the tool is of a plastic material) by electroforming (if the tool is metallic) or by an other method.

It should be noted that all figures are not to scale, and that the thickness of the original 11 in Figs. 5 and 6 is shown reduced compared to its thickness in Figs. 7 and 8. The original may be a 'conventional' master or sub-master that is to be provided with a spacer portion.

An alternative manufacturing method of a replication tool 1 is shown in Figs. 9-13. It comprises the steps of providing a master 11 (as shown in Fig. 5), replicating it so that a sub-master tool original 21 is created (Fig. 9), for example made of a plastic material such as PDMS, adding a coating layer 22 (Fig. 10) and structuring it (Fig. 11) so that the protrusions remain at the place of the spacers. The structuring may for example be done by a photolithography process using a structured resist layer 23 and an etch that does not attack the sub-master tool original material.

The resulting sub-master tool 21' shown in Fig 11 comprises the sub-master tool original 21 and the protrusions 22' remaining from the coating layer. Then, the sub-master tool 21' is replicated yielding a sub-master 24, which is shown in Fig. 13.

The procedure involving a sub-master tool and a sub-master has some additional advantages and may be used also in cases other than the process of Figs. 10-13. Since only a limited number of replicas (maybe up to a few 100) can be produced from a PDMS tool, it is important to have a constant supply of PDMS tools for mass production. However, in order to improve the life time of the master, its handling and the number of tools made from the master should be kept to a minimum. The intermediate step involving a sub-master tool and a sub-master, where the sub-master acts as master for the tool production that is used for mass production of replicas, is a suitable means. The sub-master can, for example, be made of the same epoxy as the final replica. The additional step of a sub-master leads to a further multiplication of the possible amount of replicas.

In Figs. 14-16, a process for forming a replication tool from a master or submaster is shown. The master or sub-master 31 is placed on a carrier element 32, such as a glass plate or the like, for example fastened to it (Fig. 14). Next, a liquid or viscous material 35, such as PDMS, is poured over the master or sub-master 31 to completely

cover it. Then, a rigid back plate 33 is placed on top of the material (Fig. 15). The master or sub-master may – not only in this example – additionally have a special release layer such as a Teflon® layer for easing release of the tool from the master or sub-master.

A rigid back plate serves for providing an improved stability in the replication process. It may be made of glass, Polymethylmetacrylate (PMMA), Polycarbonate (PC) or any other suitable dimensionally stiff, essentially hard material.

External spacer elements 34 cause its position to be horizontal and control the overall thickness of the replication tool. Depending on the sticking properties of the liquid or viscous material and of the rigid back plate, a glue layer (such as an epoxy layer or the like, not shown) may be placed between the rigid back plate and the liquid or viscous material. As an alternative, the back plate may be spin coated with and adhesion promoter and then dried. Then, the liquid or viscous material is hardened – in the example of a PDMS tool by drying at room temperature or at an elevated temperature – to provide a stiff tool, possibly with some residual elasticity. Finally, the master or sub-master may be removed (Fig. 16)

Of course, the method shown in Figs. 2-4 may be executed using a tool with a rigid back plate 34 as shown in the figures.

An example of a bottom view of a replication tool is shown in **Fig. 17.** The replication tool comprises a pattern of regularly arranged spacers 1c which can be located on streets for a later dicing process. Positions with negative structural features on the replicating surface 1a for replicating micro-optical components are

symbolized by filled circles. The embossing surface in this case is continuous, whereas the spacer portion comprises a plurality of discrete spacers 1a.

A typical width of a spacer is about 100-1000 μm, a typical height about 2-200 μm. Typically, the spacers are arranged in a pitch (distance between neighboring spacers) of about 0,5-20 mm.

All above described fabrication processes may be made on complete wafers (sizes: 2'' to 8'').

The replication tool of **Fig. 18**, in contrast comprises a contiguous spacer portion., whereas the replicating surface 1a' with the negative structural features consists of a plurality of discrete replicating surface sections in indentations (symbolized by rectangles with rounded edges) in the spacer portion. Replication with a tool as shown in Fig. 18 results in replicated protruding structures.

Other spacer portion shapes are possible, for example, the spacer portion may be a spacer grid, consist of a plurality of spacer rings, etc.

According to a special embodiment, the spacer portion is laid out in a manner that the fluid dynamics during the replication process is optimally controlled. For example, the spacer portion may comprise a plurality of spacers or a contiguous spacer portion arranged in one or several complete or incomplete borders or rings at the edge of an intended replication area (and at least partially surrounding it) to stop the flow of uncured replication material during the embossing process. This can be in particular required in order to prevent any replication equipment from contamination.

In a more general form of this embodiment, such described "flow stop spacers" can also act to form isolated replication areas, as well as replication areas with holes (i.e. non-replicated parts) or arbitrarily defined outlines.

As shown in **Fig. 19**, the replication tool may further comprise alignment structures, such as an alignment pin 1f or a plurality of alignment pins for positioning the replication tool in certain replication processes. The alignment pins engage in corresponding negative structures during the replication process.

Alignment is of special importance in double-sided replication processes. **Figures 20 and 21** show a schematic view of the double sided replication process. In the first method (figure 20) the two aligned tools 36, 37 are placed on top and on the bottom side of the replica in a cast robot With such an arrangement, the replication process works as follows. First, epoxy (it may, of course, be replaced by other suitable plastically deformable, viscous or liquid material) is dispensed on top of the bottom tool 37. A substrate 38 – for example made of glass or of an other transparent material – is then placed on top of the bottom tool 37 at a certain distance which determines the thickness of the replication layer on the bottom side, and which is well defined by the spacer portion,. Next, the epoxy is hardened by being exposed to UV light to complete the process of the bottom side replication. For the top side replication, epoxy is dispensed on top of the glass substrate 38. The top tool is then placed at a certain distance, well defined by the spacer portion, to the substrate to perform the top side replication. The replication process is completed after UV exposure of the top replication layer.

A further replication method is shown in **Fig. 21**. In a first step, the replication process (stamping and UV curing) is performed on the top side of the substrate. Then the substrate is turned upside down and the replication is repeated on the second side

of the substrate. During each replication process the second replication has to be aligned to the first replication. Such a process is very similar to what can currently be performed on a mask aligner.

Replication methods for double-sided elements have very strict tolerances in the front/back side alignment as well as in the replication layer thickness. Both may be as strict as in a range of 1-2 µm or even stricter. For double-sided elements, the overall planarity of the replication is very important; the requirement can be solved by the replication method and replication tools according to the invention. Further, some double sided elements, the spacer design influence on the optical function may be more pronounced than in one-sided elements.

The replication tool 101 shown – very schematically – in Fig. 22 comprises a spacer portion 1c that is not strictly regular. Further, its replication surface 101a is not confined to one level but instead is a multilevel replication surface. The replication tool 101 further comprises features 101g for forming replicated features having a mechanical function.

The embodiments shown may be varied in many ways. Especially, the described shapes and materials are mere examples; other shapes and materials and material combinations are possible. Especially, masters, sub-masters tools and/or replicas may be made up of several portions of varying material compositions.

CLAIMS

1. A process for manufacturing an element (3) having a structured surface with structural features, comprising the steps of

   a. providing a replication tool (1, 101) having, on a replication surface (1a, 1a', 101a), negative structural features being a negative of at least some of the structural features, and further having a spacer portion (1c, 1c', 101c) protruding from the replication surface surface,

   b. providing a preliminary product having a material component in a plastically deformable or viscous or liquid state, and

   c. bringing said material component in contact with said replication surface while the spacer portion abuts a stop face and thus replicating from the replication surface, the structured surface

2. A process according to claim 1, wherein after step c. the material component is hardened and thereafter the replication tool (1, 101) is removed.

3. A process according to claim 1 or 2, wherein the material component is an epoxy resin.

4. A process according to any one of the previous claims, wherein in steps b. and c. the replication tool (1, 101) is moved against the preliminary product and pressed against it until the spacers abut the stop face, whereby the replication process is an embossing process.

5. A process according to any one of claims 1-3, wherein the in steps b. and c., the replication tool (1, 101) is placed on or underneath a hard surface serving as said stop face, the spacer portions abutting said hard surface, and then said material component is injected between said replication tool and said hard surface in a viscous or liquid state.

6. A replication tool (1, 101) for manufacturing a structured element comprising structural features in a process according to any one of claims 1-5, comprising, on a replication surface (1a, 1a', 101a), negative structural features being a negative of at least some of the structural features, and further having a spacer portion (1c, 1c') protruding from the replication surface.

7. A replication tool according to claim 6, wherein the spacer portion (1c) comprises a plurality spacers arranged in a regular pattern.

8. A replication tool according to claim 6, wherein the spacer portion is contiguous.

9. A replication tool according to any one of claims 6-8, comprising elastomeric material components, for example PDMS.

10. A replication tool according to claim 9 further comprising a rigid back plate (33).

11. A replication tool according to any one of claims 6-10 further comprising alignment pins (1f).

12. A replication tool according to any one of claims 6-11, wherein the spacer portion is arranged in a manner that at least one spacer portion border is formed around a replication area in a manner that the spacer portion border at least partially borders the replication area and forms a flow stop during the replication process.

13. A method for manufacturing a replication tool (1, 101) for manufacturing structured elements having a surface with structural features, comprising the steps of providing an original having at least some of said structural features, and replicating, from the original, a tool having negative structural features being a negative of at least some of said structural features, wherein said tool is provided with a spacer portion protruding from a replication surface.

14. A method according to claim 13, wherein indentations corresponding to negatives of the spacer portion are made in the original, for example by etching.

15. A method according to claim 13, wherein the replicating of the tool comprises the steps of replicating a master tool from the original, providing the master tool with a coating layer, structuring the coating layer in a manner that it forms master protrusions corresponding to the spacer portion, replicating a submaster from the master tool and replicating the tool from the submaster.

16. A method of equipping a sub-master or master for a replication tool with a replication surface and a spacer portion, the sub-master or master comprising a master replication surface with structural features corresponding to structural features of a micro-optical component to be replicated with the replication tool,

the method comprising manufacturing from the master or sub-master an equipped master or sub-master comprising an indentation portion being the negative of a spacer portion of the replication tool, the spacer portion of the replication tool protruding from the replication surface.

ABSTRACT OF THE DISCLOSURE

According to the invention, a micro-structured element is manufactured by replicating/shaping (molding or embossing or the like) a 3D-structure in a preliminary product using an replication tool (1). The replication tool comprises a spacer portion (1c) protruding from a replication surface (1a). The replica (the micro-structured element, for example the micro-optical element or micro-optical element component) may be made of epoxy, which is cured – for example UV cured – while the replication tool is still in place. The replication process may be an embossing process, where the deformable or viscous or liquid component of the preliminary product to be shaped is placed on a surface and then the replication tool is pressed against this surface. As an alternative, the replication process may be a molding process.

(Fig. 1)

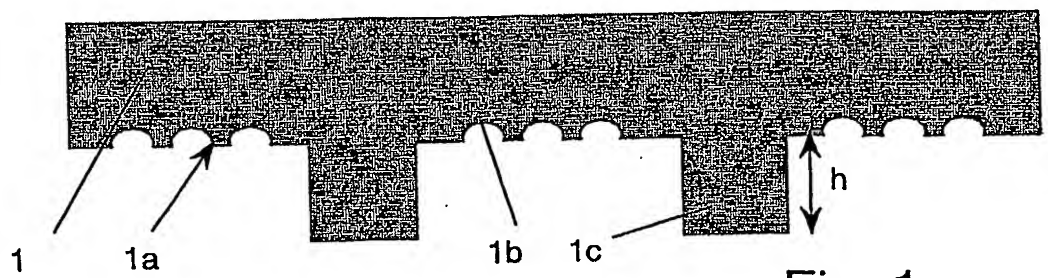

Fig. 1

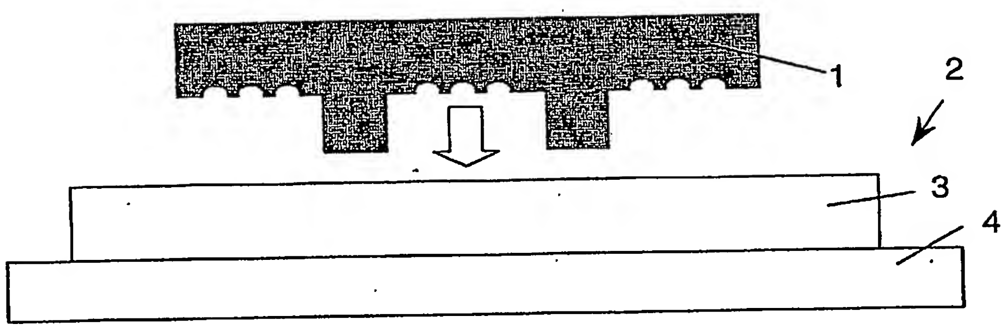

Fig. 2

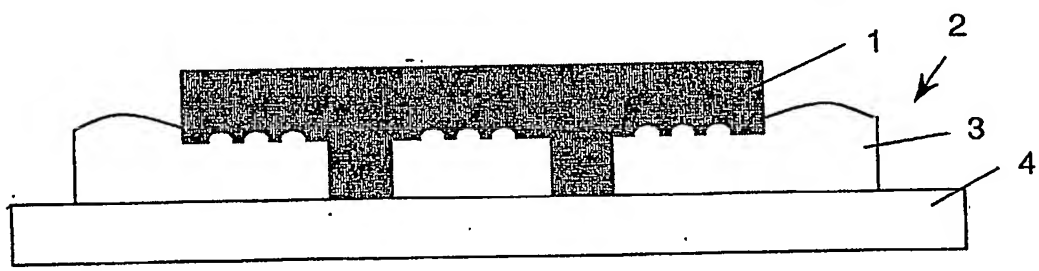

Fig. 3

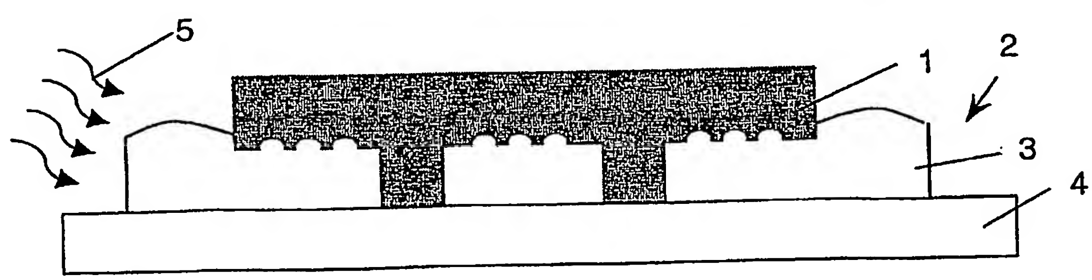

Fig. 4

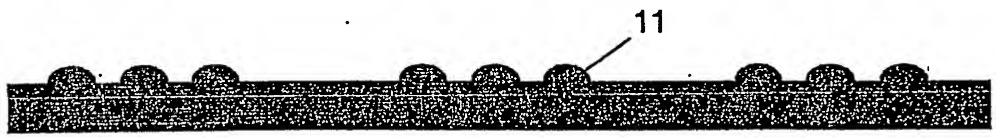

Fig. 5

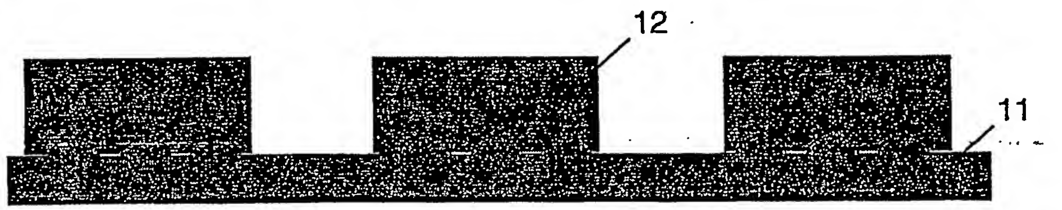

Fig. 6

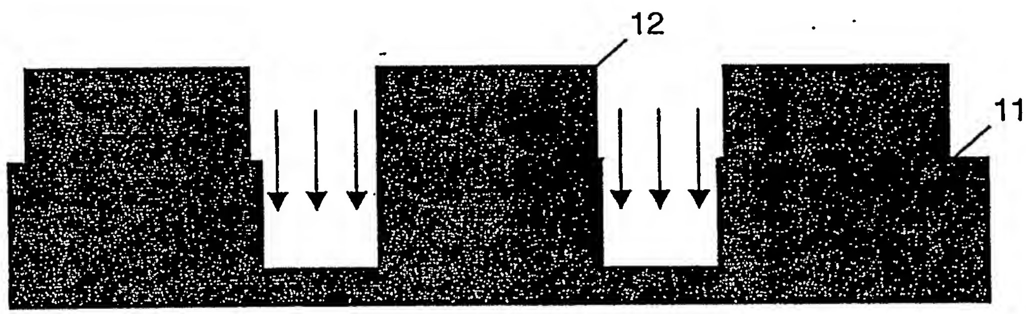

Fig. 7

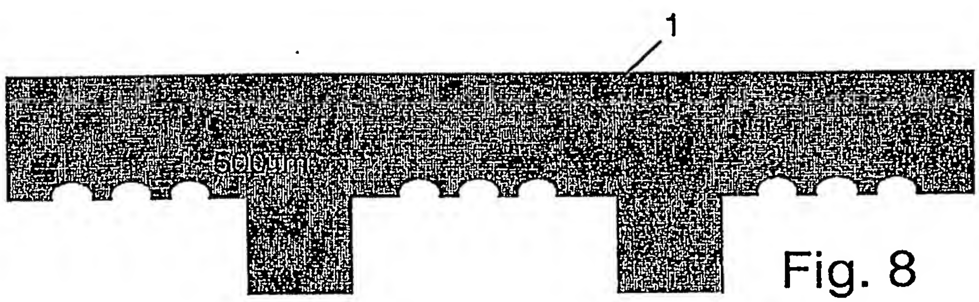

Fig. 8

Fig. 9

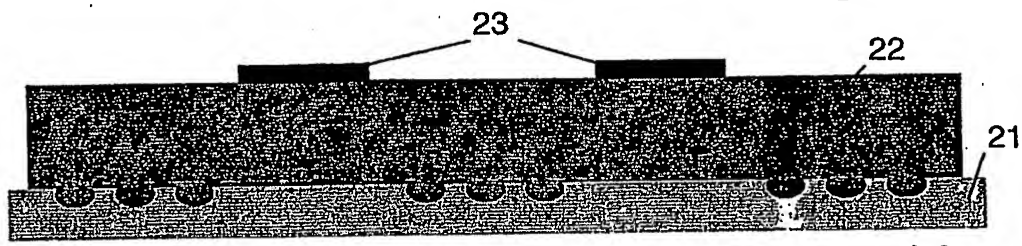

Fig. 10

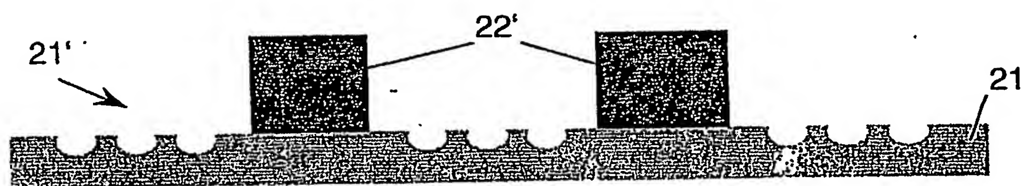

Fig. 11

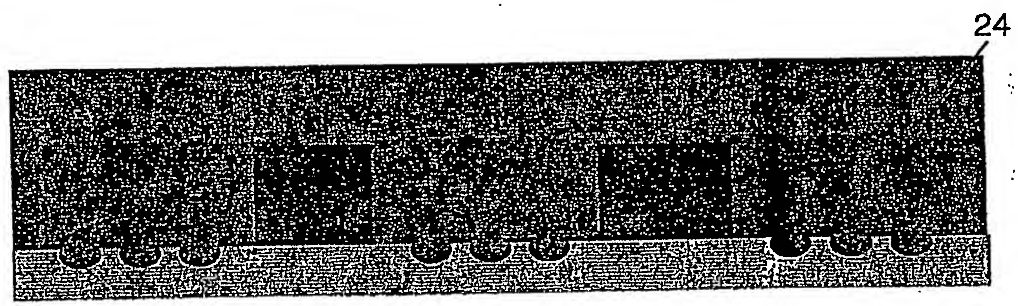

Fig. 12

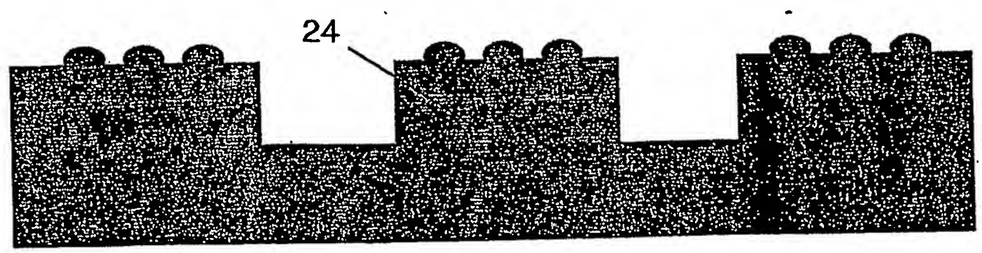

Fig. 13

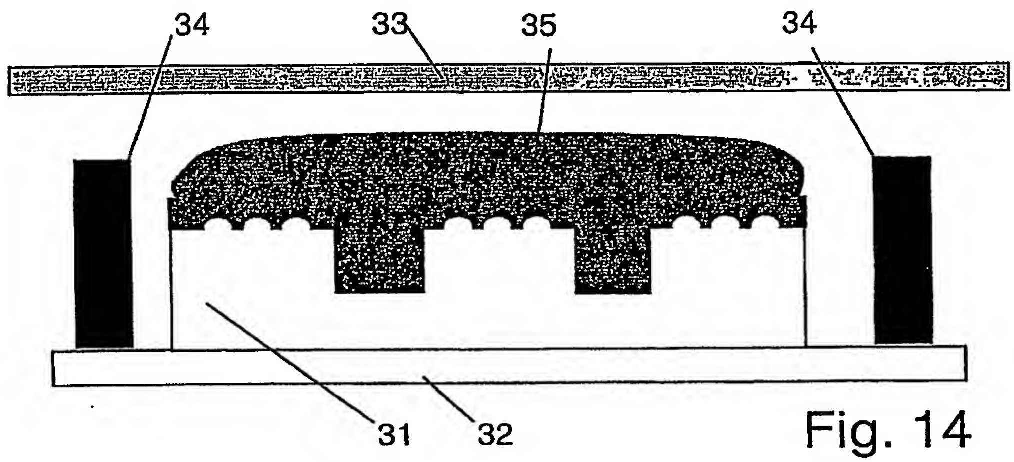

Fig. 14

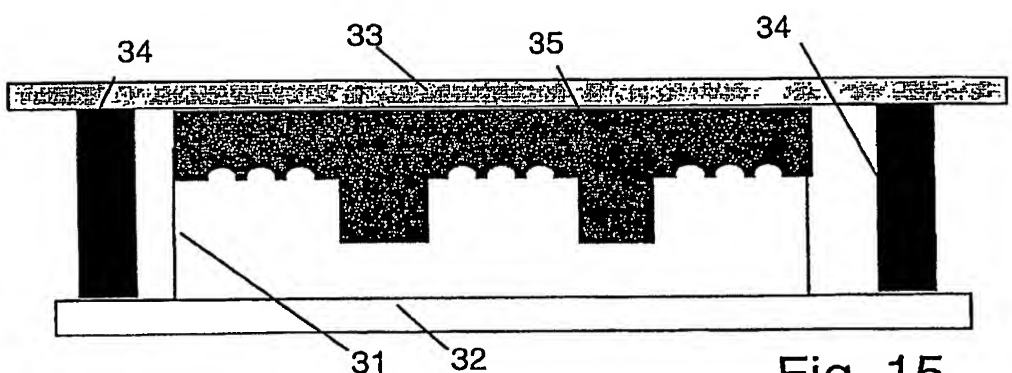

Fig. 15

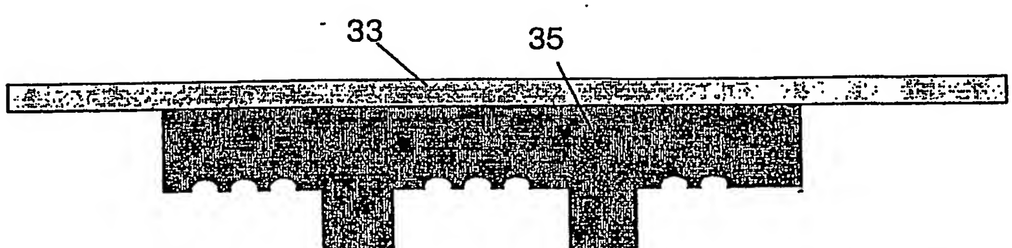

Fig. 16

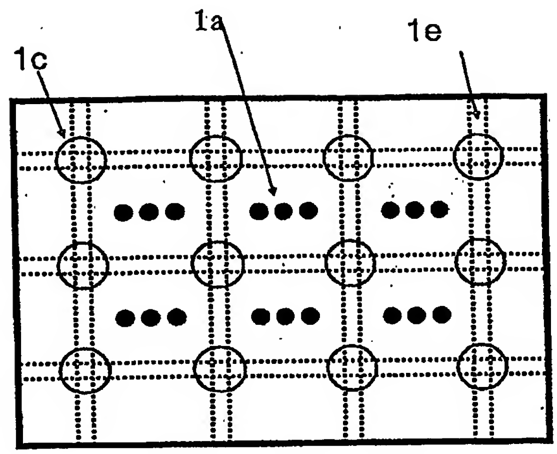

Fig. 17

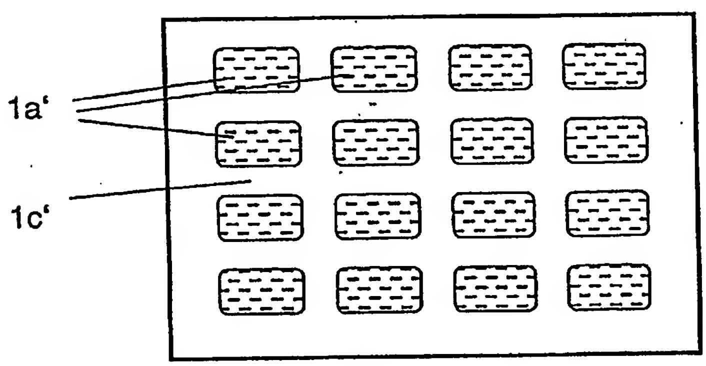

Fig. 18

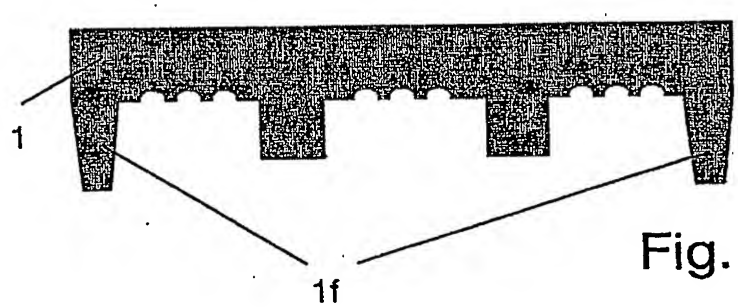

Fig. 19

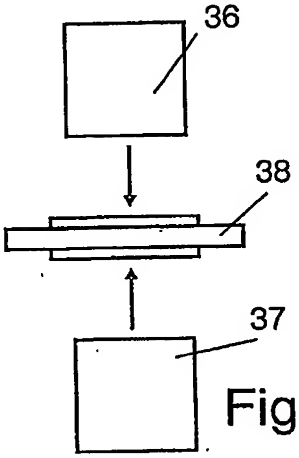

Fig. 20

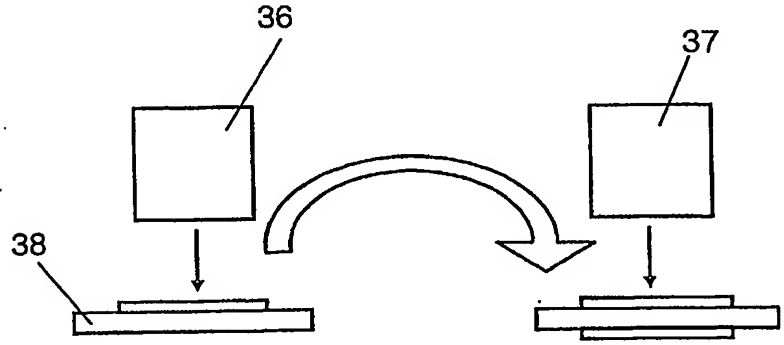

Fig. 21

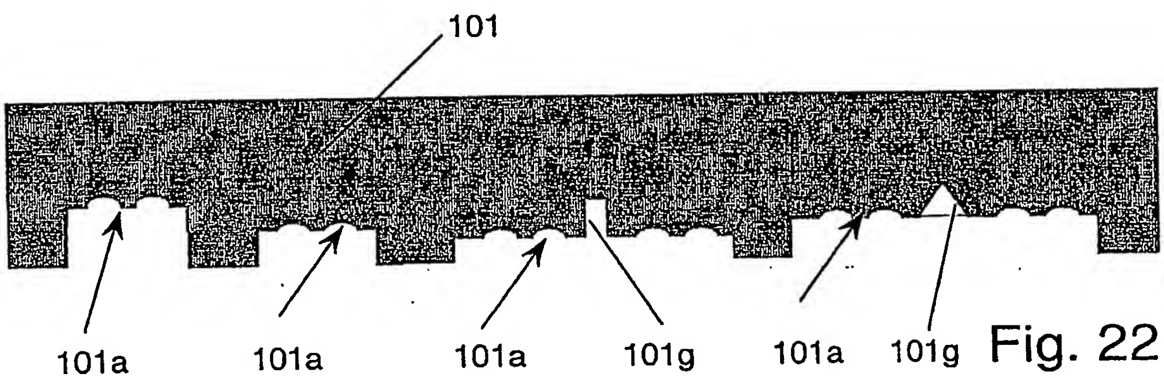

Fig. 22